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# ***U.S. PATENT APPLICATION***

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***Invention:*** CORRECTED MASK PATTERN VERIFICATION APPARATUS AND  
CORRECTED MASK PATTERN VERIFICATION

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## ***SPECIFICATION***

## BACKGROUND OF THE INVENTION

## 1. FIELD OF THE INVENTION:

The present invention relates to a corrected mask  
5 pattern verification apparatus and a corrected mask  
pattern verification method for verifying that a pattern  
of a corrected mask has been properly corrected. More  
specifically, the present invention relates to a corrected  
mask pattern verification apparatus and a corrected mask  
10 pattern verification method for verifying that correction  
of a pattern of an exposure mask in consideration of the  
influence of the optical proximity effect, generated when  
exposing the exposure mask to light, has been properly  
performed.

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## 2. DESCRIPTION OF THE RELATED ART:

In a production process of a semiconductor  
integrated circuit, photolithography is performed a  
plurality of times. In a photolithography step, a  
20 photomask is formed as an exposure mask. The photomask  
has a pattern corresponding to a layout of the semiconductor  
integrated circuit represented by design data for the  
semiconductor integrated circuit. In the  
photolithography step, the photomask is exposed to light

on a wafer so as to transfer the pattern of the layout onto the wafer.

Such a photomask generally has the same pattern  
5 as that of a light shielding portion of a photoresist layer formed on a quartz substrate. The pattern of the photomask is formed based on the pattern of the light shielding portion and a light transmitting portion of the photoresist layer.

10 Recently, as semiconductor integrated circuits are increasingly reduced in size, the patterns of the layout of the semiconductor integrated circuits are also increasingly becoming smaller. In accordance with this, the patterns of the photomasks are also becoming smaller.

15 When a pattern of a photomask is extremely small, interference caused by diffraction of light influences the pattern transferred onto the wafer. As a result, the pattern transferred onto the wafer may be significantly  
20 different from the pattern represented by the design data. In this case, malfunctions may occur, which lowers the production yield of the semiconductor integrated circuits.

Hereinafter, the influence of interference on the

pattern transferred onto the wafer will be described.

Figure 18 shows a corner of a pre-correction (original) mask 51. Figure 19 shows a corner of a pattern 52 transferred onto a wafer by exposing the pre-correction mask 51 shown in Figure 18 to light. The corner of the pattern 52 is rounded due to interference, and loses a corner portion 52a.

10 In order to suppress the influence of interference of light on the pattern transferred onto a wafer, a technology referred to as optical proximity effect correction (OPC) has been developed. The processing used by this technology (OPC processing) is performed as follows.

15 The influence of interference of light on the pattern transferred onto the wafer is evaluated by optical simulation or using test patterns transferred onto the wafer by exposure to light. Based on the evaluation results, the pattern of the photomask is corrected such

20 that the pattern transferred onto the wafer reproduces the pattern represented by the design data. The pattern transferred onto the wafer by exposing the photomask having a corrected pattern reproduces the pattern represented by the design data with higher fidelity than a photomask

having a non-corrected pattern.

Hereinafter, the OPC processing will be described.

5           Figure 20 shows a corrected mask 53 having a pattern corrected by the OPC processing. The corrected mask 53 has a projection 53a at the corner of the original mask 51 (Figure 18).

10           Figure 21 shows a corner of a pattern 54 transferred onto a wafer by exposing the corrected mask 53 shown in Figure 20 to light. The corner of the pattern 54 is rounded by interference, and loses a corner portion 54a. However, the pattern 54 obtained using the corrected mask 53  
15 reproduces the design data with higher fidelity than the pattern 52 (Figure 19) obtained using the pre-corrected mask 51.

20           There are two principal methods for correcting a pattern by the OPC processing for producing a semiconductor integrated circuit. According to method 1, the degree of correction is determined based on an optical simulation and the pattern is corrected (simulation-based OPC). According to method 2, pattern correction is performed

based on a specific rule for each pattern (rule-based OPC).

Generally, method 2 is inferior to, but consumes less time than, method 1. In general, method 1 or method 2 is used in accordance with the required precision of the pattern.

The OPC processing corrects the entire pattern of the photomask used for producing a semiconductor integrated circuit. More specifically, the photomask is divided into small regions (having sides of several micrometers to several hundred micrometers), and each of the small divided regions is corrected. Each side of each pattern is required to be sufficiently longer than the wavelength of light, but should also be appropriately short such that the amount of data is sufficiently small to be processed at one time regardless of the performance of the computer used.

The border regions between adjacent small regions may not be properly corrected for the following three reasons: (1) the adjacent small regions are corrected based on different standards; (2) the standards for correction depend on how the border line is set; and

(3) incorrect processing is performed by a correction program or a computer.

When the pattern of the photomask cannot be properly corrected, the pattern represented by the design data cannot be reproduced with high fidelity. As a result, pseudo defects are generated in the pattern of the photomask during the mask formation step, which lowers the production yield, and increases the cost of the semiconductor integrated circuits.

In order to ensure that a photomask having a properly corrected pattern is produced, methods for verifying that proper correction has been performed have been proposed.

Japanese Laid-Open Publication No. 11-174659 discloses a method for verifying that proper correction has been performed. The method disclosed in Japanese Laid-Open Publication No. 11-174659 includes the step of determining whether or not a corrected mask pattern is encompassed in a mask pattern obtained by enlarging an original mask, and the step of determining whether or not a mask pattern obtained by reducing the original mask is

encompassed in the corrected mask pattern.

Figure 22 shows the corrected mask pattern verification method disclosed in Japanese Laid-Open Publication No. 11-174659. This method will be described with reference to Figure 22.

Original mask pattern data (design mask pattern data) 11 and corrected mask pattern data (post-correction mask pattern data) 12 are input to a corrected mask pattern verification apparatus. The original mask pattern data 11 represents the pattern of an original mask. The corrected mask pattern data 12 represents the pattern of a corrected mask.

15

The original mask pattern data 11 is processed by graphic reduction operation 13, thereby generating reduced mask pattern data, and also processed by graphic enlargement operation 14, thereby generating enlarged mask pattern data.

20

The generated reduced mask pattern data and the corrected mask pattern data 12 are processed by graphic differential operation 15, thereby generating first



differential mask pattern data. The first differential mask pattern data indicates how much of a reduced mask pattern represented by the reduced mask pattern data is encompassed in a corrected mask pattern represented by the corrected mask pattern data 12.

Based on the first differential mask pattern data, determination 17 is performed, thereby generating first determination data which indicates whether or not the reduced mask pattern is encompassed in the corrected mask pattern.

The generated enlarged mask pattern data and the corrected mask pattern data 12 are processed by graphic differential operation 16, thereby generating second differential mask pattern data. The second differential mask pattern data indicates how much of the corrected mask pattern represented by the corrected mask pattern data 12 is encompassed in the enlarged mask pattern represented by the enlarged mask pattern data.

Based on the second differential mask pattern data, determination 18 is performed, thereby generating second determination data which indicates whether or not the

corrected mask pattern is encompassed in the enlarged mask pattern.

Whether or not the corrected mask has been properly  
5 corrected is determined based on the first determination  
data and the second determination data. When the first  
determination data indicates that "the reduced mask  
pattern is encompassed in the corrected mask pattern" and  
the second determination data indicates that "the  
10 corrected mask pattern is encompassed in the enlarged mask  
pattern", the corrected mask is determined to have been  
properly corrected.

Figure 23 shows an exemplary original pattern 11a  
15 represented by the original mask pattern data 11. The  
original pattern 11a is L-shaped as shown in Figure 23.

Figure 24 shows an exemplary enlarged mask pattern  
14a represented by the enlarged mask pattern data. The  
20 enlarged mask pattern 14a is also L-shaped. Each of the  
sides of the enlarged mask pattern 14a is uniformly longer  
than each corresponding side of the original mask pattern  
11a.

According to the method disclosed in Japanese Laid-Open Publication No. 11-174659, abnormal correction may not be detected. The reason is that even when the first determination data indicates that "the reduced mask pattern is encompassed in the corrected mask pattern" and  
5 the second determination data indicates that "the corrected mask pattern is encompassed in the enlarged mask pattern", the corrected mask may have been abnormally corrected.

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Such a case will be described below.

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Figure 25 shows an exemplary corrected mask pattern 55 having an unnecessary pattern 55a.

Figure 26 shows an exemplary corrected mask pattern 56 lacking a necessary pattern 56a.

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The corrected mask pattern 55 and the corrected mask pattern 56, neither of which is a properly corrected mask pattern, are both determined as a properly corrected mask pattern by the method disclosed in Japanese Laid-Open Publication No. 11-174659. The reason is that the first determination data indicates that "the reduced mask

pattern is encompassed in the corrected mask pattern" and the second determination data indicates that "the corrected mask pattern is encompassed in the enlarged mask pattern". The size of the corrected mask pattern 55 and  
5 the size of the corrected mask pattern 56 are substantially the same as the size of the proper corrected mask pattern.

Japanese Laid-Open Publication No. 11-184064 discloses a corrected mask pattern verification method  
10 for verifying that the corrected mask pattern has been properly corrected by comparing an original mask pattern and a corrected mask pattern based on an optical simulation. This method, however, increases the cost of the semiconductor integrated circuits, since the operation  
15 steps such as Fourier transform steps performed by a computer extends the processing time.

#### SUMMARY OF THE INVENTION

20 According to one aspect of the invention, a corrected mask pattern verification apparatus for verifying that corrected mask pattern data generated based on design mask pattern data has been properly corrected is provided. The corrected mask pattern verification

apparatus includes a graphic operation section for performing a prescribed graphic operation based on the design mask pattern data and the corrected mask pattern data so as to generate differential mask pattern data indicating a result of the prescribed graphic operation; 5 a graphic reduction-enlargement operation section for reducing the differential mask pattern data and enlarging the differential mask pattern data obtained by the reduction, and generating graphic reduction-enlargement operation data indicating a graphic reduction-enlargement operation result; a first determination section for determining whether or not the graphic reduction-enlargement operation data includes the differential mask pattern, and generating first 10 determination result data indicating a determination result thereof; an area comparison operation section for calculating an area of a differential mask pattern represented by the differential mask pattern data and comparing the calculated area with a prescribed area, and generating area comparison operation data indicating an 15 area comparison operation result; a second determination section for determining whether or not the area comparison operation data includes the differential mask pattern data and generating second determination result data indicating 20

a determination result thereof; and a third determination section for determining whether or not the corrected mask pattern data has been properly corrected based on the first determination result data and the second determination  
5 result data.

In one embodiment of the invention, the result of the prescribed graphic operation is a graphic difference obtained from the design mask pattern data and the corrected  
10 mask pattern data.

In one embodiment of the invention, the result of the prescribed graphic operation is a graphic exclusive-OR obtained from the design mask pattern data and the corrected  
15 mask pattern data.

According to another aspect of the invention, a corrected mask pattern verification method for verifying that corrected mask pattern data generated based on design  
20 mask pattern data has been properly corrected is provided. The corrected mask pattern verification method includes (a) a first graphic differential operation step of deleting the design mask pattern data from the corrected mask pattern data, thereby generating first differential

mask pattern data representing a first differential mask pattern; (b) a first graphic reduction-enlargement operation step of performing a first reduction on the first differential mask pattern data and then performing a first enlargement on the first mask pattern data obtained by the first reduction, thereby generating first graphic reduction-enlargement operation data indicating a first graphic reduction-enlargement operation result; (c) a first determination step of determining whether or not the first graphic reduction-enlargement operation data includes the first differential mask pattern data, thereby generating first determination result data indicating a result thereof; (d) a first area comparison operation step of calculating an area of the first differential mask pattern based on the first differential mask pattern data, and comparing the area of the first differential mask pattern with a first prescribed area, thereby generating first area comparison operation data indicating a result thereof; (e) a second determination step of determining whether or not the first area comparison operation data includes the first differential mask pattern data, thereby generating second determination result data indicating a result thereof; (f) a second graphic differential operation step of deleting the corrected mask pattern data

from the design mask pattern data, thereby generating second differential mask pattern data representing a second differential mask pattern; (g) a second graphic reduction-enlargement operation step of performing a second reduction on the second differential mask pattern data and then performing a second enlargement on the second mask pattern data obtained by the second reduction, thereby generating second graphic reduction-enlargement operation data indicating a second graphic reduction-enlargement operation result; (h) a third determination step of determining whether or not the second graphic reduction-enlargement operation data includes the second differential mask pattern data, thereby generating third determination result data indicating a result thereof; (i) a second area comparison operation step of calculating an area of the second differential mask pattern based on the second differential mask pattern data, and comparing the area of the second differential mask pattern with a second prescribed area, thereby generating second area comparison operation data indicating a result thereof; (j) a fourth determination step of determining whether or not the second area comparison operation data includes the second differential mask pattern data, thereby generating fourth determination result data



indicating a result thereof; and (k) a fifth determination step of determining whether or not the corrected mask pattern data has been properly corrected based on the first determination result data, the second determination result data, the third determination result data, and the fourth determination result data.

In one embodiment of the invention, the first reduction shortens each of the sides of the first differential mask pattern by a first prescribed amount. The first enlargement extends each of the sides of the first differential mask pattern obtained by the first reduction by a second prescribed amount. The second reduction shortens each of the sides of the second differential mask pattern by a third prescribed amount. The second enlargement extends each of the sides of the second differential mask pattern obtained by the second reduction by a fourth prescribed amount. The corrected mask pattern includes a plurality of regions. The corrected mask pattern verification method further includes (1) performing steps (a) through (k) for each of the plurality of regions. For each performance of step (1), the first prescribed amount, the second prescribed amount, the third prescribed amount, the fourth prescribed

amount, the first prescribed area, and the second prescribed area are set.

In one embodiment of the invention, the first  
5 reduction shortens each of the sides of the first  
differential mask pattern by a first prescribed amount.  
The first enlargement extends each of the sides of the  
first differential mask pattern obtained by the first  
reduction by a second prescribed amount. The second  
10 reduction shortens each of the sides of the second  
differential mask pattern by a third prescribed amount.  
The second enlargement extends each of the sides of the  
second differential mask pattern obtained by the second  
reduction by a fourth prescribed amount. The corrected  
15 mask pattern verification method further includes  
(m) performing steps (a) through (k). For each  
performance of step (m), the first prescribed amount, the  
second prescribed amount, the third prescribed amount,  
and the fourth prescribed amount are each shortened by  
20 a prescribed length. Each of the shortened first  
prescribed amount, the shortened second prescribed amount,  
the shortened third prescribed amount, and the shortened  
fourth prescribed amount is set as a maximum correction  
amount based on the result obtained by step (k) which is

performed each time step (m) is performed.

According to still another aspect of the invention,  
a corrected mask pattern verification method for verifying  
5 that corrected mask pattern data generated based on design  
mask pattern data has been properly corrected is provided.  
The corrected mask pattern verification method includes  
(a) a graphic operation step of generating a differential  
mask pattern data representing an exclusive-OR of the  
10 design mask pattern data and the corrected mask pattern  
data; (b) a graphic reduction-enlargement operation step  
of performing a reduction on the differential mask pattern  
data and then performing an enlargement on the differential  
mask pattern data obtained by the reduction, thereby  
15 generating graphic reduction-enlargement operation data  
indicating a graphic reduction-enlargement operation  
result; (c) a first determination step of determining  
whether or not the graphic reduction-enlargement operation  
data includes the differential mask pattern data, thereby  
20 generating first determination result data indicating a  
result thereof; (d) an area comparison operation step of  
calculating an area of the differential mask pattern based  
on the differential mask pattern data, and comparing the  
calculated area of the differential mask pattern with a

prescribed area, thereby generating area comparison operation data indicating a result thereof; (e) a second determination step of determining whether or not the area comparison operation data includes the differential mask pattern data, thereby generating second determination result data indicating a result thereof; and (f) a third determination step of determining whether or not the corrected mask pattern data has been properly corrected based on the first determination result data and the second determination result data.

In one embodiment of the invention, the reduction shortens each of the sides of the differential mask pattern by a first prescribed amount. The enlargement extends each of the sides of the differential mask pattern obtained by the reduction by a second prescribed amount. The corrected mask pattern includes a plurality of regions. The corrected mask pattern verification method further includes (g) performing steps (a) through (f) for each of the plurality of regions. For each performance of step (g), the first prescribed amount, the second prescribed amount, and the prescribed area are set.

In one embodiment of the invention, the reduction

shortens each of the sides of the differential mask pattern by a first prescribed amount. The enlargement extends each of the sides of the differential mask pattern obtained by the reduction by a second prescribed amount. The  
5 corrected mask pattern verification method further includes (h) performing steps (a) through (f). For each performance of step (h), the first prescribed amount and the second prescribed amount are each shortened by a prescribed length. Each of the shortened first prescribed  
10 amount and the shortened second prescribed amount is set as a maximum correction amount of the corrected mask pattern based on the result obtained by step (f) which is performed each time step (h) is performed.

15 A corrected mask pattern verification apparatus according to the present invention obtains differential mask pattern data based on a graphic difference or a graphic exclusive-OR from corrected mask pattern data and original mask pattern data. The differential mask pattern data  
20 is processed by a graphic reduction-enlargement operation and also by area comparison operation.

When the corrected mask pattern has a desired size, no differential mask pattern is left as a result of graphic

reduction-enlargement operation of the differential mask pattern data. Thus, it can be detected that the corrected mask pattern has been properly corrected.

5           When the corrected mask pattern has a size larger than a desired size, at least a portion of the differential mask pattern is left as a result of graphic reduction-enlargement operation of the differential mask pattern data. Thus, it can be detected that the corrected  
10 mask pattern has not been properly corrected.

          As a result of the area comparison operation of the differential mask pattern data, it can be determined whether or not the area of the differential mask pattern  
15 is within a prescribed range. When the area of the differential mask pattern is outside the prescribed range, the corrected mask pattern is determined not to have been properly corrected.

20           A mask pattern properly corrected reproduces the pattern of the layout of the semiconductor integrated circuit represented by the design data with high fidelity. Therefore, the resultant semiconductor integrated circuit operates properly. This improves the production yield

of, and lowers the cost of, the semiconductor integrated circuit.

Thus, the invention described herein makes  
5 possible the advantages of providing a corrected mask  
pattern verification apparatus and a corrected mask  
pattern verification method for verifying, at high speed  
and low cost, that correction of an exposure mask pattern  
in consideration of the influence of the optical proximity  
10 effect, generated when exposing the exposure mask to light,  
has been properly performed.

These and other advantages of the present  
invention will become apparent to those skilled in the  
15 art upon reading and understanding the following detailed  
description with reference to the accompanying figures.

#### BRIEF DESCRIPTION OF THE DRAWINGS

20 Figure 1 shows a structure of a corrected mask  
pattern verification apparatus 100 according to an example  
of the present invention;

Figure 2 shows an original mask pattern 61

represented by original mask pattern data 1 shown in Figure 1;

Figure 3 shows a corrected mask pattern 62  
5 represented by corrected mask pattern data 2 shown in Figure 1;

Figure 4 shows an exemplary first differential mask  
pattern represented by first differential mask pattern  
10 data;

Figure 5 shows an exemplary second differential  
mask pattern represented by second differential mask  
pattern data;  
15

Figure 6 shows mask patterns represented by  
differential mask pattern data processed by a graphic  
reduction-enlargement operation;

20 Figures 7A through 7C show an example of the area  
comparison operation performed on the differential mask  
pattern;

Figure 8 is a flowchart illustrating a corrected



mask pattern verification method according to an example  
of the present invention;

Figure 9 shows corrected mask pattern verification  
5 processing in the case where a plurality of correction  
rules are applied to one integrated circuit;

Figures 10A and 10B show exemplary evaluation  
original mask patterns;

10

Figures 11A and 11B show exemplary evaluation  
corrected mask patterns;

Figure 12 is a flowchart illustrating a method for  
15 obtaining the maximum modification width  $R_{mod}$ ;

Figure 13 shows an OPC mask pattern 62a;

Figure 14 shows an OPC mask pattern 62b;

20

Figure 15 shows an exemplary differential mask  
pattern processed by a graphic reduction-enlargement  
operation;

Figures 16A and 16B show an example of area comparison operation performed on the differential mask pattern;

5           Figure 17 shows an exemplary differential mask pattern represented by differential mask pattern data;

Figure 18 shows a corner of an original mask (pre-correction mask) 51;

10

Figure 19 shows a corner of a pattern 52 transferred by exposing the original mask 51 to light shown in Figure 18;

15           Figure 20 shows a corrected mask 53 having a pattern corrected by OPC processing;

Figure 21 shows a corner of a pattern 54 transferred by exposing the corrected mask 53 to light shown in Figure 20;

20

Figure 22 shows a conventional corrected mask pattern verification method;

Figure 23 shows an exemplary original mask pattern represented by an original mask pattern 11 shown in Figure 22;

5           Figure 24 shows an enlarged mask pattern represented by enlarged mask pattern data;

Figure 25 shows an exemplary corrected mask pattern having an unnecessary portion; and  
10

Figure 26 shows an exemplary corrected mask pattern lacking a necessary portion.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

15

Hereinafter, the present invention will be described by way of illustrative examples with reference to the accompanying drawings.

20           Figure 1 shows a structure of a corrected mask pattern verification apparatus 100 according to an example of the present invention.

The corrected mask pattern verification apparatus

100 includes a graphic differential operation section 3,  
a graphic reduction-enlargement operation section 4, an  
area comparison operation section 5, a first determination  
section 6, a second determination section 7, and a third  
5 determination section 8.

The graphic differential operation section 3  
receives original mask pattern data (design mask pattern  
data) 1 and corrected mask pattern data (post-correction  
10 mask pattern data) 2. The original mask pattern data 1  
represents the pattern of an original mask. The corrected  
mask pattern data 2 represents the pattern of a corrected  
mask.

15 Based on the original mask pattern data 1 and the  
corrected mask pattern data 2, the graphic differential  
operation section 3 performs a prescribed graphic  
differential operation and generates differential mask  
pattern data, which represents the result of the prescribed  
20 graphic differential operation. The differential mask  
pattern data represents at least a part of a portion which  
is different between the original mask pattern data 1 and  
the corrected mask pattern data 2.

The differential mask pattern data is output from the graphic differential operation section 3 to the graphic reduction-enlargement operation section 4 and the area comparison operation section 5.

5

The graphic reduction-enlargement operation section 4 processes the differential mask pattern data with a graphic reduction-enlargement operation. The graphic reduction-enlargement operation is an operation of reducing the differential mask pattern represented by the differential mask pattern data and enlarging the reduced differential mask pattern.

When the size of the differential mask pattern is equal to the size to be applied for correction (desired size), there is no differential mask pattern left after the reduction. Therefore, the graphic reduction-enlargement operation section 4 outputs data which does not include the post-graphic reduction-enlargement operation differential mask pattern data to the first determination section 6. When the size of the differential mask pattern is larger than the size to be applied for correction, there is a portion of the differential mask pattern left after the reduction.

Therefore, the graphic reduction-enlargement operation section 4 outputs data which includes the post-graphic reduction-enlargement operation differential mask pattern data to the first determination section 6.

5

The first determination section 6 determines whether or not the data which is output from the graphic reduction-enlargement operation section 4 includes the post-graphic reduction-enlargement operation differential mask pattern data, and generates first determination data. The first determination data indicates whether or not the data which is output from the graphic reduction-enlargement operation section 4 to the first determination section 6 includes the post-graphic reduction-enlargement operation differential mask pattern data.

10  
15

The first determination section 6 then outputs the first determination data to the third determination section 8.

20

The area comparison operation section 5 processes the differential mask pattern data which is output from the graphic differential operation section 3 with area

comparison operation. The area comparison operation is an operation of calculating the area of the differential mask pattern based on the differential mask pattern data and comparing the area of the differential mask pattern and a prescribed area.

When the area of the differential mask pattern is outside a prescribed area range, the area comparison operation section 5 outputs data which includes the differential mask pattern data to the second determination section 7. When the area of the differential mask pattern is within the prescribed area range, the area comparison operation section 5 outputs data which does not include the differential mask pattern data to the second determination section 7.

The second determination section 7 determines whether or not the data which is output from the area comparison operation section 5 includes the differential mask pattern data, and generates second determination data. The second determination data indicates whether or not the data which is output from the area comparison operation section 5 to the second determination section 7 includes the differential mask pattern data.

Based on the first determination data and the second determination data, the third determination section 8 determines whether or not the corrected mask pattern has been properly corrected. The third determination section 8 then generates final determination result data 9. The final determination result data 9 indicates whether or not the corrected mask pattern data 2 represents the properly corrected mask pattern.

10

When the final determination result data indicates that "the corrected mask pattern data 2 represents the properly corrected mask pattern", the corrected mask pattern verification apparatus 100 determines that correction of the corrected mask has been properly performed.

15

Hereinafter, how a mask pattern is processed by the graphic differential operation section 3, the graphic reduction-enlargement operation section 4, the area comparison operation section 5, the first determination section 6, the second determination section 7, and the third determination section 8 will be described in detail.

20



Figure 2 shows an original mask pattern 61 represented by original mask pattern data. The original mask pattern 61 is polygonal.

5           Figure 3 shows a corrected mask pattern 62 represented by the corrected mask pattern data 2.

The corrected mask pattern 62 is generated by OPC-processing the original mask pattern 61. The  
10   corrected mask pattern 62 includes OPC mask patterns 62a at convex corners of the original mask pattern 61 and an OPC mask pattern 62b at a concave corner of the original mask pattern 61. The OPC mask patterns 62a are projecting, and the OPC mask pattern 62b is recessed. Owing to the  
15   OPC mask patterns 62a and 62b, the corners of the pattern transferred onto a wafer by exposing the corrected mask pattern 62 can be prevented from being rounded.

The graphic differential operation section 3  
20   obtains a graphic difference between the original mask pattern data 1 and the corrected mask pattern data 2 by the graphic operation. The graphic differential operation section 3 generates the differential mask pattern data, which represents the obtained graphic

difference.

The graphic difference is obtained from two types of mask pattern data which are to be subjected to the operation. More specifically, the graphic difference is a pattern obtained by deleting one type of data from the other type of data. For example, when the two types of data each have a plurality of bits, the pattern is obtained by subtracting the logical value of each of the plurality of bits of one type of data from the logical value of the corresponding bit of the other type of data. It is assumed that the result of subtraction of the logical value "1" from the logical value "0" is the logical value "0". The subtraction is represented by the following logical operations.

Logical value "1" - logical value "1" = logical value "0"  
Logical value "1" - logical value "0" = logical value "1"  
Logical value "0" - logical value "1" = logical value "0"  
Logical value "0" - logical value "0" = logical value "0"

The graphic differential operation section 3 generates first differential mask pattern data by deleting the original mask pattern data 1 from the corrected mask

pattern data 2. The graphic differential operation section 3 also generates second differential mask pattern data by deleting the corrected mask pattern data 2 from the original mask pattern data 1.

5

The first differential mask pattern data and the second differential mask pattern data are output to the graphic reduction-enlargement operation section 4. The first differential mask pattern data and the second differential mask pattern data are also output to the area comparison operation section 5.

10

Figure 4 shows a first differential mask pattern or an OPC mask pattern 62a (hatched portion) represented by the first differential mask pattern data, obtained by the graphic differential operation section 3 by deleting data representing the original mask pattern 61 (Figure 2) from data representing the corrected mask pattern 62 (Figure 3).

15

20

Figure 5 shows a second differential mask pattern or an OPC mask pattern 62b (hatched portion) represented by the second differential mask pattern data, obtained by the graphic differential operation section 3 by deleting

data representing the corrected mask pattern 62 (Figure 3) from the data representing the original mask pattern 61 (Figure 2).

5           The present invention is not limited to generating both the first differential mask pattern data and the second differential mask pattern data. For example, when there is no graphic difference obtained by deleting the original mask pattern data 1 from the corrected mask pattern data  
10   2, the first differential mask pattern data does not need to be generated. When there is no graphic difference obtained by deleting the corrected mask pattern data 2 from the original mask pattern data 1, the second differential mask pattern data does not need to be  
15   generated.

          The graphic reduction-enlargement operation section 4 processes each of the first differential mask pattern data and the second differential mask pattern data  
20   with the graphic reduction-enlargement operation. As described above, the graphic reduction-enlargement operation is an operation of reducing the differential mask pattern represented by the differential mask pattern data and enlarging the reduced differential mask pattern.

The reduction processing shortens the length of each of the sides of each differential mask pattern by a prescribed amount. The enlargement processing extends  
5 the length of each of the sides of each differential mask pattern by a prescribed amount.

When the size of the differential mask pattern is equal to the size to be applied for correction, there is  
10 no differential mask pattern left after the reduction. The reason is that each side of the differential mask pattern is shorter than the prescribed amount by which the length of each side is shortened. In this case, data which does not include the post-graphic reduction-enlargement  
15 operation differential mask pattern data is output to the first determination section 6.

When the size of the differential mask pattern is larger than the size to be applied for correction, at least  
20 a portion of the differential mask pattern is left after the reduction. The reason is that each side of the differential mask pattern is longer than the prescribed amount by which the length of each side is shortened. In this case, data which includes the post-graphic

reduction-enlargement operation differential mask pattern data is output to the first determination section 6.

5                Figure 6 shows mask patterns represented by the differential mask pattern data processed by the graphic reduction-enlargement operation.

10              Pattern 6(a) is a differential mask pattern which is larger than the size to be applied for correction. Pattern 6(b) is generated by reducing pattern 6(a). Since pattern 6(a) is larger than the size to be applied for correction, at least a portion of the differential mask pattern is left after reduction. Pattern 6(c) is generated  
15              by enlarging pattern 6(b).

                As described above, the first determination section 6 determines whether or not the data which is output from the graphic reduction-enlargement operation section  
20              4 includes the post-graphic reduction-enlargement operation differential mask pattern data. Then, the first determination section 6 generates and outputs first determination data to the third determination section 8. The first determination data indicates whether or not the

data which is output from the graphic  
reduction-enlargement operation section 4 to the first  
determination section 6 includes the post-graphic  
reduction-enlargement operation differential mask  
5 pattern data.

When the size of the differential mask pattern is  
larger than the size to be applied for correction, the  
corrected mask pattern verification apparatus 100 can  
10 verify that the corrected mask pattern has been properly  
corrected by processing the differential mask pattern by  
a graphic reduction-enlargement operation. By contrast,  
when the size of the differential mask pattern is smaller  
than or equal to the size to be applied for correction,  
15 it cannot be verified that the corrected mask pattern has  
been properly corrected simply by processing the  
differential mask pattern by the graphic  
reduction-enlargement operation. The reason is that no  
differential mask pattern is left after reduction.

20

In order to overcome this inconvenience, the  
correctedmaskpatternverificationapparatus100 includes  
the area comparison operation section 5.

The area comparison operation section 5 compares the area of the first differential mask pattern data and the area of the second differential mask pattern data. The area comparison operation calculates an area of a differential mask pattern based on differential mask pattern data and compares the calculated area with a prescribed area.

More specifically, the area comparison operation section 5 calculates an area of the first differential mask pattern based on the first differential mask pattern data, and compares the area of the first differential mask pattern with the prescribed area. The area comparison operation section 5 calculates an area of the second differential mask pattern based on the second differential mask pattern data, and compares the area of the second differential mask pattern with the prescribed area.

As described above, when the area of the differential mask pattern is outside the prescribed area range, the area comparison operation section 5 outputs data which includes the differential mask pattern data to the second determination section 7. When the area of the differential mask pattern is within the prescribed



area range, the area comparison operation section 5 outputs data which does not include the differential mask pattern data to the second determination section 7.

5                Figures 7A through 7C show examples of the area comparison operation performed on the differential mask pattern.

              Pattern 7(a) shown in Figure 7A is a differential  
10    mask pattern which is represented by differential mask  
              pattern data which is input to the area comparison operation  
              section 5. The area comparison operation section 5  
              calculates area  $S_a$  of pattern 7(a) based on the differential  
              mask pattern data. Then, the area comparison operation  
15    section 5 compares area  $S_a$ , area  $S_1$  and area  $S_2$ . Area  $S_1$   
              and area  $S_2$  define the prescribed area range. In this  
              example, area  $S_a$ , area  $S_1$  and area  $S_2$  have the relationship  
              of  $S_1 \leq S_a \leq S_2$ , and therefore the area comparison operation  
              section 5 outputs data which does not include the  
20    differential mask pattern data to the second determination  
              section 7.

              Pattern 7(b) shown in Figure 7B is another  
              differential mask pattern which is represented by another

differential mask pattern data which is input to the area comparison operation section 5. The area comparison operation section 5 calculates area  $S_b$  of pattern 7(b) based on the differential mask pattern data. Then, the area comparison operation section 5 compares area  $S_b$ , area  $S_1$  and area  $S_2$ . In this example, area  $S_b$  and area  $S_1$  have the relationship of  $S_b < S_1$ , and therefore the area comparison operation section 5 outputs data which includes the differential mask pattern data to the second determination section 7.

Pattern 7(c) shown in Figure 7C is still another differential mask pattern which is represented by still another differential mask pattern data which is input to the area comparison operation section 5. The area comparison operation section 5 calculates area  $S_c$  of pattern 7(c) based on the differential mask pattern data. Then, the area comparison operation section 5 compares area  $S_c$ , area  $S_1$  and area  $S_2$ . In this example, area  $S_c$  and area  $S_2$  have the relationship of  $S_2 < S_c$ , and therefore the area comparison operation section 5 outputs data which includes the differential mask pattern data to the second determination section 7.

As described above, the second determination section 7 determines whether or not the data which is output from the area comparison operation section 5 includes the differential mask pattern data. Then, the second determination section 7 generates and outputs second determination data to the third determination section 8. The second determination data indicates whether or not the data which is output from the area comparison operation section 5 to the second determination section 7 includes the differential mask pattern data.

When the data which is output from the area comparison operation section 5 to the second determination section 7 does not include the differential mask pattern data, that means that the area of the differential mask pattern is within the prescribed area range. Therefore, the second determination section 7 determines that "the corrected mask pattern has the desired shape."

Owing to the area comparison operation section 5, the corrected mask pattern verification apparatus 100 can verify a pattern which is smaller than a desired pattern and thus cannot be verified by the graphic reduction-enlargement operation section 4.

The third determination section 8 determines whether or not the corrected mask pattern has been properly corrected, based on the first determination data and the second determination data. The third determination section 8 generates and outputs final determination result data, which indicates whether or not the corrected mask pattern data 2 represents the pattern of the properly corrected mask. When the final determination result data indicates that "the corrected mask pattern data 2 represents the pattern of the properly corrected mask", the corrected mask pattern verification apparatus 100 determines that correction of the corrected mask has been properly performed.

15

In the case where the first determination data indicates that "the data which is output from the graphic reduction-enlargement operation section 4 to the first determination section 6 does not include the differential mask pattern data processed by graphic reduction-enlargement operation" and the second determination data indicates that "the data which is output from the area comparison operation section 5 to the second determination section 7 does not include the differential

20

mask pattern data", the final determination result data which is output from the third determination section 8 shows that the corrected mask pattern has been properly corrected.

5

Figure 8 is a flowchart illustrating a corrected mask pattern verification method according to the example of the present invention. With reference to Figure 8, each step of the corrected mask pattern verification method will be described in detail.

10

Step 1: The graphic differential operation section 3 generates first differential mask pattern data  $\Delta A$ , which represents the graphic difference obtained from the original mask pattern data 1 and the corrected mask pattern data 2; more specifically, the graphic difference obtained by deleting the original mask pattern data 1 from the corrected mask pattern data 2.

15

The graphic differential operation section 3 outputs the first differential mask pattern data  $\Delta A$  to the graphic reduction-enlargement operation section 4, and also to the area comparison operation section 5.

20

Step 2: The graphic reduction-enlargement operation section 4 reduces the first differential mask pattern data  $\Delta A$ , thereby generating data  $\Delta A1$ . This processing shortens each side of the differential mask pattern by length  $R_a$ . Length  $R_a$  is the maximum amount by which each side can be expected to be shortened when proper correction is performed.

Step 3: The graphic reduction-enlargement operation section 4 extends data  $\Delta A1$ , thereby generating data  $\Delta A2$ . This processing extends each side of the differential mask pattern by length  $R_a$ .

The data processed by the graphic reduction-enlargement operation is output from the graphic reduction-enlargement operation section 4 to the first determination section 6.

When at least a part of data  $\Delta A2$  is left ( $\Delta A2 \neq 0$ ), the data processed by the graphic reduction-enlargement operation includes data  $\Delta A2$ . When data  $\Delta A2$  is not left ( $\Delta A2 = 0$ ), the data processed by the graphic reduction-enlargement operation does not include data  $\Delta A2$ .

Step 4: The first determination section 6 determines whether or not the data processed by the graphic reduction-enlargement operation includes data  $\Delta A2$ .

5

When the data processed by the graphic reduction-enlargement operation includes data  $\Delta A2$ , the processing goes to step 11, since in this case, abnormal correction has been performed. In step 11, the corrected mask pattern is modified as necessary.

10

When the data processed by the graphic reduction-enlargement operation does not include data  $\Delta A2$ , the processing goes to step 5.

15

Step 5: The area comparison operation section 5 calculates area  $S_A$  of the first differential mask pattern based on the differential mask pattern data  $\Delta A$ . Then, the area comparison operation section 5 compares area  $S_A$ , area  $S_{amin}$ , and area  $S_{amax}$ .

20

When area  $S_A$ , area  $S_{amin}$ , and area  $S_{amax}$  have the relationship of  $S_{amin} \leq S_A \leq S_{amax}$ , the processing goes to step 6.

When area  $S_A$  and area  $S_{amin}$  have the relationship of  $S_A < S_{amin}$ , the processing goes to step 11. When area  $S_A$  and area  $S_{amax}$  have the relationship of  $S_{amax} < S_A$ , the  
5 processing also goes to step 11.

Area  $S_{amin}$  is the minimum area of the differential mask pattern which is expected when proper correction is performed. Area  $S_{amax}$  is the maximum area of the  
10 differential mask pattern which is expected when proper correction is performed.

After this, the second differential mask pattern  $\Delta B$  is processed in steps 6 through 10 in substantially  
15 the same manner as that of processing the first differential mask pattern  $\Delta A$  in steps 1 through 5.

Step 6: The graphic differential operation section 3 generates second differential mask pattern data  $\Delta B$ , which  
20 represents the graphic difference obtained from the original mask pattern data 1 and the corrected mask pattern data 2; more specifically, the graphic difference obtained by deleting the corrected mask pattern data 2 from the original mask pattern data 1.



The graphic differential operation section 3 outputs the second differential mask pattern data  $\Delta B$  to the graphic reduction-enlargement operation section 4, and also to the area comparison operation section 5.

Step 7: The graphic reduction-enlargement operation section 4 reduces the second differential mask pattern data  $\Delta B$ , thereby generating data  $\Delta B1$ . This processing shortens each side of the differential mask pattern by length  $Rb$ . Length  $Rb$  is the maximum amount by which each side can be expected to be shortened when proper correction is performed.

Step 8: The graphic reduction-enlargement operation section 4 extends data  $\Delta B1$ , thereby generating data  $\Delta B2$ . This processing extends each side of the differential mask pattern by length  $Rb$ .

The data processed by the graphic reduction-enlargement operation is output from the graphic reduction-enlargement operation section 4 to the first determination section 6.

When at least a part of data  $\Delta B2$  is left ( $\Delta B2 \neq 0$ ), the data processed by the graphic reduction-enlargement operation includes data  $\Delta B2$ . When data  $\Delta B2$  is not left ( $\Delta B2 = 0$ ), the data processed by a graphic reduction-enlargement operation does not include data  $\Delta B2$ .

Step 9: The first determination section 6 determines whether or not the data processed by the graphic reduction-enlargement operation includes data  $\Delta B2$ .

When the data processed by a graphic reduction-enlargement operation includes data  $\Delta B2$ , the processing goes to step 11, since in this case, abnormal correction has been performed. In step 11, the corrected mask pattern is modified as necessary.

When the data processed by the graphic reduction-enlargement operation does not include data  $\Delta B2$ , the processing goes to step 10.

Step 10: The area comparison operation section 5 calculates area  $S_b$  of the second differential mask pattern based on the differential mask pattern data  $\Delta B$ . Then,

the area comparison operation section 5 compares area  $S_B$ , area  $S_{bmin}$ , and area  $S_{bmax}$ .

When area  $S_B$ , area  $S_{bmin}$ , and area  $S_{bmax}$  have the  
5 relationship of  $S_{bmin} \leq S_B \leq S_{bmax}$ , the processing is properly terminated.

When area  $S_B$  and area  $S_{bmin}$  have the relationship  
of  $S_B < S_{bmin}$ , the processing goes to step 11. When area  
10  $S_B$  and area  $S_{bmax}$  have the relationship of  $S_{bmax} < S_B$ , the processing also goes to step 11.

Area  $S_{bmin}$  is the minimum area of the differential mask pattern which is expected when proper correction is  
15 performed. Area  $S_{bmax}$  is the maximum area of the differential mask pattern which is expected when proper correction is performed.

In the above example, a graphic difference is used  
20 for obtaining a differential mask pattern based on an original mask pattern and a corrected mask pattern. Alternatively, a graphic exclusive-OR may be used for obtaining a differential mask pattern. In this case, processing of extracting non-matching portions between

the original mask pattern and the corrected mask pattern is carried out.

When a graphic exclusive-OR is used, values Ra and  
5 Rb used by the graphic reduction-enlargement operation section need to be adapted to the largest pattern. Values Samin, Samax, Sbmin and Sbmax used by the area comparison operation also need to be adapted to the largest pattern.

10 In general, a mask pattern correction amount in accordance with a certain rule is used for all the mask patterns in a logic integrated circuit. However, when regularly arranged mask patterns (for example, mask patterns in memory cells in a memory integrated circuit)  
15 are included in mask patterns of a logic integrated circuit, a correction amount which is optimum for the pattern regularity is used for the regularly arranged mask patterns, and a correction amount which is different from the optimum correction amount is used for the mask patterns which are  
20 different from those in the memory cells in the memory integrated circuit.

In the case where the correction amount is determined based on a certain rule, values Ra and Rb used

by the graphic reduction-enlargement operation section and values Samin, Samax, Sbmin and Sbmax used by the area comparison operation section may be determined in accordance with each of a plurality of regions included in the corrected mask pattern. Since these values are determined in this manner, the corrected mask pattern can be verified more accurately. When the corrected mask pattern is determined for an integrated circuit having two or more different correction rules, appropriate values can be set in accordance with each of the plurality of regions.

Figure 9 shows corrected mask pattern verification processing in the case where a plurality of correction rules are applied to one integrated circuit.

Step 21: The corrected mask pattern verification apparatus 100 selects region 1 which uses a specific correction rule, from a plurality of regions of the mask pattern. The selected region 1 is referred to as region P1. When a plurality of regions which use different correction rules from each other are included in one mask pattern, that one mask pattern generally includes a pattern covering each of the plurality of regions. The region

using the specific correction rule can be selected by addition of the pattern covering each of the plurality of regions and a graphic pattern.

5           After the corrected mask pattern verification apparatus 100 selects region P1, the processing goes to step 22.

10           Step 22: The corrected mask pattern verification apparatus 100 performs substantially the same processing as that of steps 1 through 10 (Figure 8) for the selected region P1. Values Ra, Samin, Samax, Rb, Sbmin and Sbmax are expected when proper correction is performed for region P1 (i.e., values Ra, Samin, Samax, Rb, Sbmin and Sbmax  
15           are inherent values of region P1).

          When it is determined that "region P1 has not been properly corrected", the processing goes to step 23. When it is determined that "region P1 has been properly  
20           corrected", the processing goes to step 24.

          Step 23: Since it is determined that "region P1 has not been properly corrected", the processing is terminated.

Step 24: The corrected mask pattern verification apparatus 100 selects region 2 which uses a specific correction rule, from a plurality of regions of the mask pattern. The selected region 2 is referred to as region P2. After the corrected mask pattern verification apparatus 100 selects region P2, the processing goes to step 25.

Step 25: The corrected mask pattern verification apparatus 100 performs substantially the same processing as that of steps 1 through 10 (Figure 8) for the selected region P2. Values Ra, Samin, Samax, Rb, Sbmin and Sbmax are the expected values when proper correction is performed for region P2 (i.e., values Ra, Samin, Samax, Rb, Sbmin and Sbmax are inherent values of region P2).

When it is determined that "region P2 has not been properly corrected", the processing goes to step 26. When it is determined that "region P2 has been properly corrected", the processing goes to step 27.

Step 26: Since it is determined that "region P2 has not been properly corrected", the processing is

terminated.

After this, the corrected mask pattern verification apparatus 100 performs substantially the same processing as that of steps 21 through 23 (Figure 8) for an arbitrary region n.

Step 27: The corrected mask pattern verification apparatus 100 selects region n which uses a specific correction rule, from a plurality of regions of the mask pattern. The selected region n is referred to as region Pn. After the corrected mask pattern verification apparatus 100 selects region Pn, the processing goes to step 28.

15

Step 28: The corrected mask pattern verification apparatus 100 performs substantially the same processing as that of steps 1 through 10 (Figure 8) for the selected region Pn. Values Ra, Samin, Samax, Rb, Sbmin and Sbmax are the expected values when proper correction is performed for region Pn (i.e., values Ra, Samin, Samax, Rb, Sbmin and Sbmax are inherent values of region Pn).

20

When it is determined that "region Pn has not been



properly corrected", the processing goes to step 29. When it is determined that "region Pn has been properly corrected", it is determined that "regions 1 through n have been properly corrected" and the processing is properly terminated.

Step 29: Since it is determined that "region Pn has not been properly corrected", the processing is terminated.

10

In the case where the correction amount is determined based on simulation, as in the case where the correction amount is determined based on a certain rule, values Ra and Rb used by the graphic reduction-enlargement operation section and values Samin, Samax, Sbmin and Sbmax used by the area comparison operation section can be determined in accordance with each of a plurality of regions included in the corrected mask pattern. Based on, for example, the minimum pattern permitted by the design rule which defines the design of the original mask pattern, the maximum correction amount can be determined.

Figures 10A and 10B show exemplary evaluation original mask patterns. An original mask pattern 71 shown

in Figure 10A and an original mask pattern 72 shown in Figure 10B are both evaluation original mask patterns. The width of the original mask pattern 71 is the minimum line width permitted by the design rule, and the area of the original mask pattern 71 is the minimum area permitted by the design rule.

The original mask pattern 72 includes the minimum space permitted by the design rule, and also the minimum junction area permitted by the design rule.

Distinctive patterns such as memory cell patterns can be, for example, created for evaluation original mask patterns (test patterns) instead of the original mask patterns 71 and 72. An evaluation original mask pattern is OPC-processed based on simulation so as to create an evaluation corrected mask pattern.

Figures 11A and 11B show exemplary evaluation corrected mask patterns. A corrected mask pattern 73 shown in Figure 11A and a corrected mask pattern 74 shown in Figure 11B are both an evaluation corrected mask pattern.

The evaluation original mask pattern 71 (Figure

10A) is OPC-processed based on simulation so as to create the evaluation corrected mask pattern 73. The evaluation corrected mask pattern 73 includes an OPC pattern 73a.

5           The evaluation original mask pattern 72 (Figure 10B) is OPC-processed based on simulation so as to create the evaluation corrected mask pattern 74. The evaluation corrected mask pattern 74 includes an OPC pattern 74a.

10           In the case where the correction amount is determined based on simulation, the correction amount of the mask pattern is determined by optical model calculation, and thus the mask pattern is corrected. The amount of correction performed on the minimum mask pattern which  
15 is permitted by the design rule is set as the maximum correction amount. For example, the maximum correction amount of the corrected mask pattern 73 is the maximum modification width Ramod.

20           Figure 12 is a flowchart illustrating a method for obtaining the maximum modification width Ramod.

Step 31: The corrected mask pattern verification apparatus 100 sets value  $Ra_0$  as the maximum value (initial

value). Value  $Ra_0$  is sufficiently larger than the modification amount which can be optically expected. After the corrected mask pattern verification apparatus 100 sets value  $Ra_0$ , the processing goes to step 32.

5

Step 32: The corrected mask pattern verification apparatus 100 performs substantially the same processing as that of steps 1 through 10 (Figure 8). As values other than value  $Ra_0$  (values  $Rb$ ,  $Samin$ ,  $Sbmin$ ,  $Samax$ ,  $Sbmax$ ),  
10 such values that will not cause errors in each step are set. For example,  $Rb = 10 \mu m$ ,  $Samin = Sbmin = 0 \mu m^2$ , and  $Samax = Sbmax = 10 \mu m^2$ .

When the corrected mask pattern verification  
15 apparatus 100 determines in step 32 that "the corrected mask pattern has been abnormally corrected", the processing goes to step 33. When the corrected mask pattern verification apparatus 100 determines in step 32 that "the corrected mask pattern has been properly  
20 corrected", the processing goes to step 34.

Step 33: The corrected mask pattern verification apparatus 100 terminates the processing.

Step 34: The corrected mask pattern verification apparatus 100 sets a value obtained by deleting  $\Delta R_a$  from  $R_{a_0}$  set as the maximum value (initial value), as value  $R_{a_1}$ . After the corrected mask pattern verification apparatus  
5 100 sets value  $R_{a_1}$ , the processing goes to step 35.

Step 35: The corrected mask pattern verification apparatus 100 performs substantially the same processing as that of steps 1 through 10 (Figure 8). As values other  
10 than value  $R_{a_1}$  (values  $R_b$ ,  $S_{amin}$ ,  $S_{bmin}$ ,  $S_{amax}$ ,  $S_{bmax}$ ), such values that will not cause errors in each step are set.

When the corrected mask pattern verification  
15 apparatus 100 determines in step 35 that "the corrected mask pattern has been abnormally corrected", the processing goes to step 36. When the corrected mask pattern verification apparatus 100 determines in step 35 that "the corrected mask pattern has been properly  
20 corrected", the processing goes to step 37.

Step 36: The corrected mask pattern verification apparatus 100 terminates the processing.

Then, the corrected mask pattern verification apparatus 100 performs substantially the same processing as that of steps 34 through 36 while decreasing the value  $R_a$  by  $\Delta R_a$ .

5

Step 37: The corrected mask pattern verification apparatus 100 sets a value obtained by deleting  $(n \times \Delta R_a)$  from  $R_{a_0}$ , as value  $R_{a_n}$ . After the corrected mask pattern verification apparatus 100 sets value  $R_{a_n}$ , the processing goes to step 38.

10

Step 38: The corrected mask pattern verification apparatus 100 performs substantially the same processing as that of steps 1 through 10 (Figure 8). As values other than value  $R_{a_n}$  (values  $R_b$ ,  $S_{amin}$ ,  $S_{bmin}$ ,  $S_{amax}$ ,  $S_{bmax}$ ), such values that will not cause errors in each step are set.

15

When the corrected mask pattern verification apparatus 100 determines in step 38 that "the corrected mask pattern has been abnormally corrected", the processing goes to step 39. When the corrected mask pattern verification apparatus 100 determines in step 38 that "the corrected mask pattern has been properly

20

corrected", the processing is properly terminated.

Step 39: the corrected mask pattern verification apparatus 100 terminates the processing.

5

When the minimum unit of the design grid of the original mask pattern (virtual coordinate defining the minimum shape of the mask pattern) is  $0.01\ \mu\text{m}$  and  $R_{\text{mod}} = 0.16$  (Figure 11), the initial value  $R_a$  is decreased by value  $\Delta R_a$  (optically considered to be sufficiently large). For example,  $R_a$  is decreased from 0.30 by  $\Delta R_a = 0.01$ . When value  $R_a = 0.16$  or greater, no differential mask pattern is left as a result of the graphic reduction-enlargement operation. Accordingly, the corrected mask pattern is found to have been properly performed. When value  $R_a = 0.15$  or smaller, at least a portion of the differential mask pattern is left as a result of the graphic reduction-enlargement operation. Therefore, the corrected mask pattern is found to have been abnormally performed.

10

15

20

Using the above-described method, the correction amount can be determined based on simulation.

The value  $R_a$  used for graphic reduction-enlargement operation is determined as described above. The other values ( $R_b$ ,  $S_{amin}$ ,  $S_{bmin}$ ,  $S_{amax}$ ,  $S_{bmax}$ ) are also determined similarly.

5

The correction amount is determined only once when the design rule is determined. Using the determined value, the corrected mask pattern can be verified by the method described above with reference to Figure 8.

10

As described above, according to the corrected mask pattern verification apparatus of the present invention, data representing a graphic differential pattern or data representing an graphic exclusive-OR pattern is produced based on the data representing the corrected mask pattern and the data representing the original mask pattern. The data representing the graphic differential pattern or the data representing graphic exclusive-OR pattern is processed by a graphic reduction-enlargement operation, and also by an area comparison operation. Accordingly, it can be verified at high speed and low cost that the corrected mask pattern has been properly corrected according to the present invention.

20



The corrected mask pattern verification method according to the present invention performs verification of a corrected mask pattern by graphic operations. Accordingly, the time period required for calculation by the corrected mask pattern verification method of the present invention is reduced several times or several ten times than the time period required for calculation by the method disclosed in Japanese Laid-Open Publication No. 11-184064; i.e., the method of verifying that the corrected mask pattern by comparing an original mask pattern and a corrected mask pattern based on optical simulation. Accordingly, it can be verified at high speed and low cost that the corrected mask pattern has been properly corrected according to the present invention.

15

Hereinafter, an operation of the corrected mask pattern verification apparatus 100 according to the present invention will be specifically described.

20

The corrected mask pattern 62 (Figure 3) has OPC mask patterns 62a and 62b in order to prevent the corners of the pattern transferred onto the wafer as a result of the mask exposure from being rounded. The OPC mask pattern 62a projects from a convex corner of the corrected mask

pattern 62. Herein, the amount by which the differential mask pattern is projecting from a convex corner of the original mask pattern or recessed from a concave corner of the original mask pattern is defined as the "projecting amount". The projecting amount of the OPC mask pattern 62a is 0.04  $\mu\text{m}$ , and the "overlapping amount" of the OPC mask pattern 62a is 0.10  $\mu\text{m}$ . The OPC mask pattern 62b is recessed from a concave corner of the corrected mask pattern 62. The projecting amount of the OPC mask pattern 62b is 0.06  $\mu\text{m}$ , and the "overlapping amount" of the OPC mask pattern 62b is 0.10  $\mu\text{m}$ .

Figure 13 shows the OPC mask pattern 62a in more detail. The OPC mask pattern 62a is obtained by the graphic differential operation section 3 by deleting the data representing the original mask pattern data 61 (Figure 2) from the data representing the corrected mask pattern data 62 (Figure 3).

Figure 14 shows the OPC mask pattern 62b in more detail. The OPC mask pattern 62b is obtained by the graphic differential operation section 3 by deleting the data representing the corrected mask pattern data 62 (Figure 3) from the data representing the original mask pattern

data 61 (Figure 2).

Hereinafter, the verification performed by the  
graphic reduction-enlargement operation section 4 will  
5 be described.

As described above, the projecting amount of the  
OPC mask pattern 62a (Figure 13) is 0.04  $\mu\text{m}$ . The graphic  
reduction-enlargement operation section 4 reduces each  
10 side of the OPC mask pattern 62a by 0.02  $\mu\text{m}$ , which is half  
of 0.04  $\mu\text{m}$ . After the reduction, the graphic  
reduction-enlargement operation section 4 enlarges each  
side of the reduced OPC mask pattern 62a by 0.02  $\mu\text{m}$ .

15 When no OPC mask pattern (the hatched portion of  
Figure 13) is left as a result of the graphic  
reduction-enlargement operation, it is determined that  
"the corrected mask pattern has been properly corrected".

20 Again as described above, the projecting amount  
of the OPC mask pattern 62b (Figure 14) is 0.06  $\mu\text{m}$ . The  
graphic reduction-enlargement operation section 4 reduces  
each side of the OPC mask pattern 62b by 0.03  $\mu\text{m}$ , which  
is half of 0.06  $\mu\text{m}$ . After the reduction, the graphic

reduction-enlargement operation section 4 enlarges each side of the reduced OPC mask pattern 62b by 0.03  $\mu\text{m}$ .

When no OPC mask pattern (the hatched portion of Figure 14) is left as a result of the graphic reduction-enlargement operation, it is determined that "the corrected mask pattern has been properly corrected".

Figure 15 shows an exemplary differential mask pattern processed by a graphic reduction-enlargement operation.

Pattern 15(a) is generated by the graphic differential operation section 3 by deleting the original mask pattern data from the corrected mask pattern data. Pattern 15(a) is a differential mask pattern which is larger than the pattern to be applied for correction. Pattern 15(a) is obtained when the correction is not properly performed. The projecting amount of pattern 15(a) is 0.06  $\mu\text{m}$ .

Pattern 15(b) is generated by reducing pattern 15(a) by 0.02  $\mu\text{m}$  by the graphic reduction-enlargement operation section 4. Since pattern 15(a) is larger than

the pattern to be applied for correction, there is a portion of pattern 15(a) (a portion having a projection amount of 0.06  $\mu\text{m}$ ) left after the reduction.

5           Pattern 15(c) is generated by enlarging pattern 15(b) by 0.02  $\mu\text{m}$  by the graphic reduction-enlargement operation section 4. Since pattern 15(a) is larger than the pattern to be applied for correction, data including data representing pattern 15(c) is output to the first  
10           determination section 6 from the graphic reduction-enlargement operation section 4.

          The first determination section 6 determines that "the shape of the corrected mask pattern is different from  
15           the desired shape".

          Hereinafter, the verification performed by the area comparison operation section 5 will be described. Figures 16A and 16B show an example of area comparison  
20           operation performed on the differential mask pattern.

          Pattern 16(a) shown in Figure 16A corresponds to the OPC mask pattern 62a (Figure 13). Pattern 16(a) is represented by the differential mask pattern which is input

to the area comparison operation section 5. Pattern 16(a) has the size of the mask pattern to be applied for correction, and Figure 16A shows the case where the correction has been properly performed.

5

The area of pattern 16(a) is  $0.096 \mu\text{m}^2$ . The area comparison operation section 5 compares  $0.096 \mu\text{m}^2$  with the minimum value and the maximum value of the prescribed area range for the area. In this example, the minimum value is  $0.009 \mu\text{m}^2$  and the maximum value is  $0.100 \mu\text{m}^2$ . Since  $0.096 \mu\text{m}^2$  is within the range, the corrected mask pattern is determined to have been properly corrected.

Pattern 16(b) shown in Figure 16b is smaller than the mask pattern to be applied for correction, and Figure 16B shows the case where the correction has not been properly performed.

The area of pattern 16(b) is  $0.004 \mu\text{m}^2$ . The area comparison operation section 5 compares  $0.004 \mu\text{m}^2$  with the minimum value and the maximum value of the prescribed area range for the area. Since  $0.004 \mu\text{m}^2$  is smaller than the minimum value of the range, the area comparison operation section 5 outputs data including pattern 16(b) to the second

determination section 7. The second determination section 7 determines that "the corrected mask pattern is different from the desired shape."

5           In the above example, a graphic difference is used for obtaining a differential mask pattern based on an original mask pattern and a corrected mask pattern. Alternatively, a graphic exclusive-OR may be used for obtaining a differential mask pattern. In this case, the operation for finding the differential mask pattern is performed only once, which is time-saving.

          When a graphic exclusive-OR is used, values used by the operation need to be adapted to the largest pattern. Therefore, the precision is lower than that when the graphic difference is used.

          Figure 17 shows an exemplary differential mask pattern represented by the differential mask pattern data.

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          When a graphic exclusive-OR is used, length Ra used by the graphic reduction-enlargement operation section 4 needs to be adapted to the largest pattern 62b. When the projecting amount of the pattern 62b is 0.06  $\mu\text{m}$ , length

Ra needs to be shortened to 0.03  $\mu\text{m}$ , which is half of the projecting amount. Therefore, when the projecting amount of the pattern 62a is larger than 0.06  $\mu\text{m}$ , it can be detected that the correction of the mask pattern has not been properly performed. When the projecting amount of the pattern 62a is smaller than 0.06  $\mu\text{m}$ , it cannot be detected that the correction of the mask pattern has not been properly performed even if the correction of the mask pattern has not been properly performed due to the pattern 62a.

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It is preferable that a graphic difference or a graphic exclusive-OR are used in accordance with the required detection precision, verification time permitted or the like.

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As described above, a corrected mask pattern verification apparatus according to the present invention processes a differential mask pattern obtained based on the graphic difference (which is obtained based on the original mask pattern data and the corrected mask pattern data) or based on the graphic exclusive-OR by a graphic reduction-enlargement operation and also by area comparison operation. Therefore, when a mask pattern for exposure is corrected in consideration of the influence

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of the optical proximity effect which occurs when exposing the mask, the corrected mask pattern verification apparatus of the present invention can check whether or not the "corrected mask pattern has been properly  
5 corrected" at high speed and low cost.

In addition, the corrected mask pattern verification apparatus of the present invention can check whether or not "the corrected mask pattern is appropriate  
10 for the production process of a semiconductor integrated circuit" with very high precision, without using optical simulation requiring a long calculation time and thus increasing the cost.

15 When the corrected mask pattern has been properly corrected, such a mask pattern reproduces the pattern of the layout of the semiconductor integrated circuit represented by the design data with high fidelity. Therefore, the resultant semiconductor integrated circuit  
20 operates properly. This improves the production yield of, and lowers the cost of, the semiconductor integrated circuit.

Various other modifications will be apparent to

and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as  
5 set forth herein, but rather that the claims be broadly construed.